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COMPACTION STUDY OF ZERO-SLUMP CONCRETE

by

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Tests were conducted at the U. S. Army Engineer Waterways Experiment Station in September 1975 to determine the effectiveness of vibratory and static compaction rollers in the compaction of zero-slump portland cement concrete pavements. It was determined that heavy vibratory rollers were very effective in compacting the dry-mix concrete and that the strength properties (compressive strength and flexural strength) were somewhat higher than would have been obtained with a conventional mix of the same cement content having

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20. ABSTRACT (Continued).

a slump in excess of 1 in. The surface smoothness, surface texture, and riding quality of the pavement were considered adequate for wearing surfaces of secondary roads and streets, haul roads, service entrances, tank trails, etc., and as a base for any pavement system. Indications are that considerable cost reductions in the construction of portland cement concrete pavements can be realized by use of dry (zero-slump) concrete mixtures placed and spread by base course or asphalt spreaders and compacted with heavy vibratory rollers.

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Preface

The study reported herein was sponsored by the Office, Chief of Engineers, U. S. Army (OCE), under military construction Project No. 4K078012AQ61, "Compaction Study of Zero-Slump Concrete." The study was conducted during the period September 1975-March 1976.

Engineers of the U. S. Army Engineer Waterways Experiment Station (WES) who were actively engaged in the planning, testing, and reporting phases of this study were Messrs. Ronald L. Hutchinson, Alfred H. Joseph, Kenneth L. Saucier, and Cecil D. Burns. The work was performed under the general supervision of Messrs. James P. Sale and Richard G. Ahlvin, Chief and Assistant Chief, respectively, of the Soils and Pavements Laboratory. Mr. A. F. Muller was technical monitor for OCE. This report was prepared by Mr. Burns.

Directors of WES during the conduct of the study and preparation of this report were COL G. H. Hilt, CE, and COL John L. Cannon, CE. Mr. F. R. Brown was Technical Director.

Contents

Conversion Factors, U. S. Customary to Metric (SI) Units of Measurement

U. S. customary units of measurement can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	25.4	millimetres
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
cubic yards	0.7645549	cubic metres
tons (2000 lb mass)	907.1847	kilograms
pounds (mass)	0.4535924	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic metre
pounds (force) per square inch	6.894757	kilopascals
pounds (force) per square inch per inch	27.144713	pascals per metre

COMPACTION STUDY OF ZERO-SLUMP CONCRETE

Introduction

Background

1. The cost of constructing portland cement concrete pavements is continually rising due to increasing costs of both labor and materials. A concept involving the use of zero-slump (dry-mix) concrete as a pavement has been under consideration at the U. S. Army Engineer Waterways Experiment Station (WES) for some time. Dry-mix concrete has been used successfully in England as a base course of both rigid and flexible pavements and has also been investigated for use in concrete dams. It is theorized that with proper proportioning a dry concrete mix will produce higher strengths at lower cement factors than the more plastic concretes. The water content of concrete is normally higher than necessary for cement hydration simply to provide workability and to permit consolidation, which is normally achieved with vibrators. Thus, if consolidation can be achieved using vibratory or static compaction rollers as opposed to internal or pan-type vibrators, it may be possible to reduce the water content and increase the concrete strength, which would result in a cost savings. However, probably the most attractive facet of dry-mix concrete would be that construction cost could be reduced since there would be no need for side forms and expensive paving trains.

Objectives

2. The objectives of this study were (a) to determine the effectiveness of vibratory and static compaction rollers in the compaction of zero-slump portland cement concrete and (b) to evaluate the strength and surface smoothness of the compacted pavement.

Scope

3. The objectives of the study were accomplished by the construction of a test section of zero-slump concrete which was incorporated into a newly constructed road at WES. Two different vibratory rollers,

a Buffalo-Bomag BW210-A (Photo 1) and a Dynapac CC-50A (Photo 2), were used in the study. A 25-ton,* self-propelled, pneumatic-tired roller (Photo 3) was also used in compacting one item of the test section for comparison purposes. For each of the vibratory compactors, two thicknesses of pavement (6 and 10 in.) were placed and compacted. Only a 6-in. thickness was compacted with the pneumatic-tired roller. Test specimens were cut from the pavement and tested in the laboratory after 28 days for the determination of density and strength properties.

Test Section

4. The test section (Plate 1) was 105 ft long by 12 ft wide and consisted of four test items, each 15 ft long. A 15-ft transition was provided between items 1 and 2 and between items 3 and 4 which was used for stopping and reversing the different rollers. The subgrade consisted of a lean clay soil having an in-place CBR of about 10 or a modulus of soil reaction k of about 185 psi/in.

Concrete mixture

5. The aggregate used in the concrete mixture was a 1-1/2-in. maximum-size crushed limestone, and the cement was type I portland cement (Federal Specification SS-C-19 2G). Trial mixes in the laboratory resulted in the following mixture:

Component or Ratio	Amount per cu yd
Cement	517 lb
Limestone coarse aggregate	2350 lb
Limestone fine aggregate	1250 lb
Water-cement ratio	0.33 by weight
Sand-aggregate ratio	0.35 by volume

The theoretical unit weight was 161.27 pcf. Twenty 2-cu-yd batches were mixed in a stationary batch plant at WES and transported in dump

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

trucks to the test site, a distance of about 1 mile.

Placement of concrete

6. Although zero-slump concrete can be placed using a simple base course spreader and even by end-dumping the concrete and spreading with a motor patrol, for this study the concrete mixture was placed on the subgrade with an available Barber-Green asphalt finisher (Photo 4). Initially a 4-in.-thick lift was placed in the area designed for the 10-in. thickness and was not compacted (Plate 1). An uncompacted lift approximately 7 in. thick was then placed over the entire test section starting at station 1+05 and proceeding toward station 0+00. The concrete was placed in a continuous 12-ft-wide lane with no transverse joints.

Compaction of concrete

7. Compaction of the concrete mixture was started on items 4 and 5 with the BW210-A vibratory roller as soon as placement of the 7-in.-thick loose lift proceeded far enough into the transition area between items 3 and 4 to permit stopping and reversing the roller in the transition area. The small capacity of the available mixer plus the long haul distance resulted in a time lag of about 1 hour from the start of placement of concrete in the initial 4-in. bottom lift until the time of compaction rolling on the surface of the 11-in. uncompacted concrete.

8. The drum width of both the BW210-A and the CC-50A rollers is 84 in., and the same rolling pattern was used for both rollers. The rolling pattern was as follows: The roller was started with one edge of the drum extending slightly over the edge of the concrete lane and traveled in the forward direction into the transition area, where it was stopped and reversed; it then returned in the same track (Photo 5). The roller was then shifted laterally to the opposite side of the lane, and the same procedure was followed. This pattern resulted in two passes of the roller over the entire width of the paving lane with some overlaps in the center. The first two passes of the roller were made using only the static weight of the roller. Six to eight additional passes were then applied with the drum vibrating. The BW210-A roller was operated at a maximum frequency of 2000 vibrations per minute (vpm) and

at one-half to maximum amplitude. The CC-50A roller was operated at a frequency of 2400 vpm and at maximum amplitude. Some water was applied to the drums during the rolling operations. In item 1, the CC-50A roller was used as a static roller (without vibration) for two passes of breakdown rolling, and then six passes of the 25-ton, pneumatic-tired roller with a 90-psi tire pressure were applied. Final rolling was accomplished by an additional two passes of the CC-50A with no vibration.

Visual observations

9. The concrete mixture appeared quite stable under the different compaction rollers. There was no tendency for shoving or displacement of the material except for a slight depression in the transition areas where the rollers stopped and reversed. This could be eliminated on an actual job by staggering the location for stopping and reversing the roller. There appeared to be good consolidation of the dry concrete mix under the external vibration of both vibratory rollers. The 7-in. uncompacted thickness consolidated to a compacted thickness of about 5 in., and the 11-in. uncompacted lift consolidated to a thickness of 8.5 to 9 in. The vibratory rollers had a tendency to work the fines to the surface, and the water applied to the vibrating drums resulted in a slurry which filled the surface voids as indicated in Photo 6. The pneumatic-tired roller left a more open textured surface.

10. The compacted pavement was moist-cured for a period of 7 days.

Density and Strength Determinations

11. Core samples and beam samples were cut from each item of the pavement and tested for the determination of unit weight, void content, compressive strength, splitting tensile strength, and flexural strength. A summary of the test results is shown in Table 1. From these data, it can be seen that both vibratory rollers were more effective in compacting the concrete mix than was the static-weight, pneumatic-tired roller. The densities and strengths developed by the two vibratory rollers were about equal except for the 10-in. pavement in item 3 which was compacted with the CC-50A roller. The lower density and strength values for this

item are probably due to the degree of drying of the concrete prior to compaction (the bottom 4 in. of this item was placed first and there was a time lapse of more than 1 hour prior to compaction rolling).

12. The average void content produced by the two vibratory rollers was 4.2 percent, which is slightly higher than would be expected in normal non-air-entrained concrete consolidated by internal vibration. However, the splitting tensile and flexural strengths are comparable to strengths obtained on conventional 5000-psi concrete; i.e., 10 and 15 percent of the compressive strength, respectively.

13. It is estimated that, to obtain a strength comparable to that obtained with the dry mix used in this study, a conventional concrete with a 1- to 2-in. slump would have required one additional bag of cement per cubic yard. This would require a water-cement ratio of about 0.45. Full optimization of mixture proportions could conceivably result in greater savings in cement. However, even greater savings could be realized through the labor and construction costs associated with zero-slump concrete.

Performance

14. As previously stated, the zero-slump concrete was placed as a continuous slab 12 ft wide by 105 ft long. No shrinkage cracks developed in the pavement during a 28-day curing period. Beam samples were cut from the pavement for 28-day strength tests, and consequently the length of the slabs was reduced to about 30 to 50 ft since two of the test beams were cut across the pavement for the full 12-ft width. The trenches where beams were removed were backfilled with fresh portland cement concrete. Subsequently, the pavement was subjected to vehicular traffic for 4 months and no visual cracks or other defects developed. The fact that no cracks developed in the 105-ft-long slab during the first days of the curing period or in the pavement after cutting beams, due to expansion, contraction, or load, may be significant. It appears that a dry (zero-slump) portland cement concrete mix is less susceptible to volume change and cracking than a conventional wet mix with a slump in excess of 1 in.

Conclusions

15. Based on the test results presented herein, the following conclusions are believed warranted.

- a. Dry-mix (zero-slump) portland cement concrete can be adequately compacted by rolling with heavy vibratory compaction rollers.
- b. Satisfactory placement of zero-slump concrete can be accomplished with a conventional base course spreader or asphalt finisher.
- c. Comparable strengths can be obtained in a properly designed zero-slump concrete mixture using less cement than that required for a conventional wet mix with a 1- to 2-in. slump.
- d. Satisfactory surface texture, smoothness, and riding quality of zero-slump concrete pavements can be obtained for wearing surfaces of secondary roads and streets or for base courses in any pavement construction using conventional base course or asphalt spreading equipment for laydown and vibratory rollers for compaction. Although not tested, it is believed that satisfactory surfaces can be obtained using end-dumped concrete spread with a motor patrol and compacted using vibratory rollers.
- e. A considerable reduction in construction cost of portland cement concrete can be realized by use of a dry concrete mixture compacted with heavy vibratory rollers.
- f. The amount of cracking from drying, shrinkage, and subsequent expansion and contraction can be reduced using the dry concrete mixture.
- g. More study is needed to determine requirements for expansion and contraction joints and construction techniques for longitudinal joints where needed.
- h. The subject of durability should be investigated since road surfaces may be susceptible to scaling and, in colder climates, to freeze-thaw deterioration.

Table 1

Summary of Results (28-Day Tests)

Test Item	Type Roller	Nominal Depth in.	Unit Weight pcf (3)	Void Content Percent (3)	Compressive Strength psi (2)	Splitting Strength psi (1)	Flexural Strength psi (1)
1	Pneumatic tired	6	148.3	8.1	2700	340	620
2	CC-50A	6	154.5	4.1	5660	615	785
3	CC-50A	10	152.6	5.4	3940	385	710
4	BW210-A	10	154.6	4.1	5880	465	755
5	BW210-A	6	156.4	3.0	4170	590	755
Average of CC-50A and BW210-A			153.3	4.2	4910	515	750

NOTE: Numbers in parentheses indicate number of individual tests conducted for each value reported.

Photo 1. Buffalo-Bomag BW210-A vibratory roller

Photo 2. Dynapac CC-50A vibratory roller

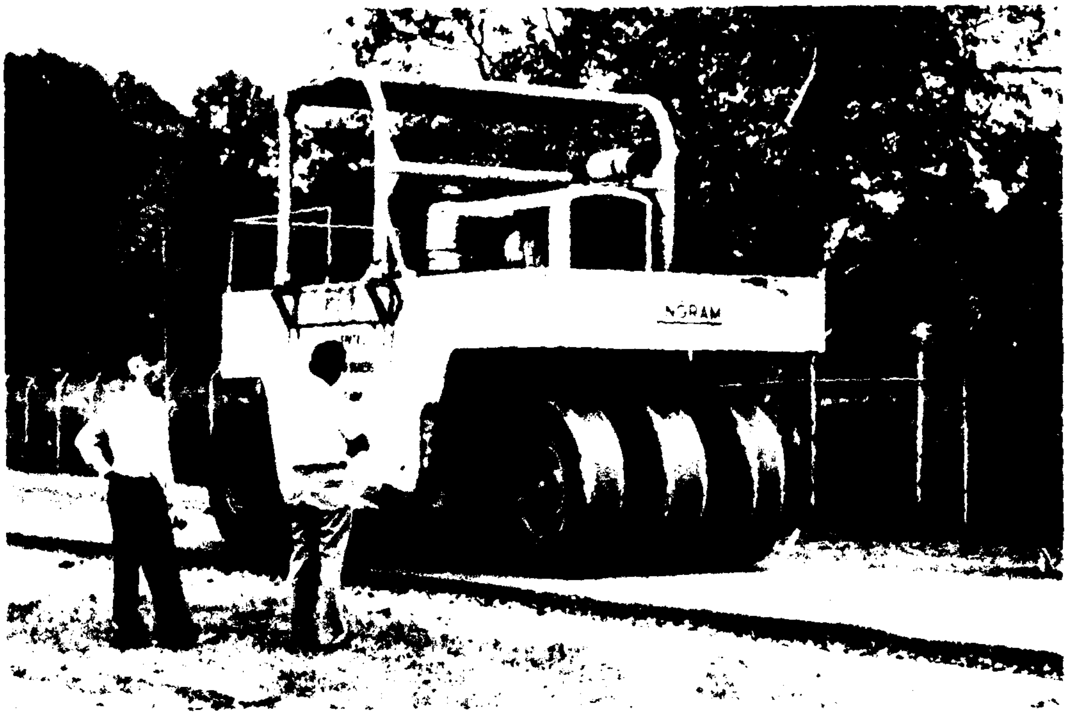


Photo 3. 25-ton, self-propelled, pneumatic-tired roller

Photo 4. Barber-Green asphalt finisher

Photo 5. Rolling pattern with vibratory rollers

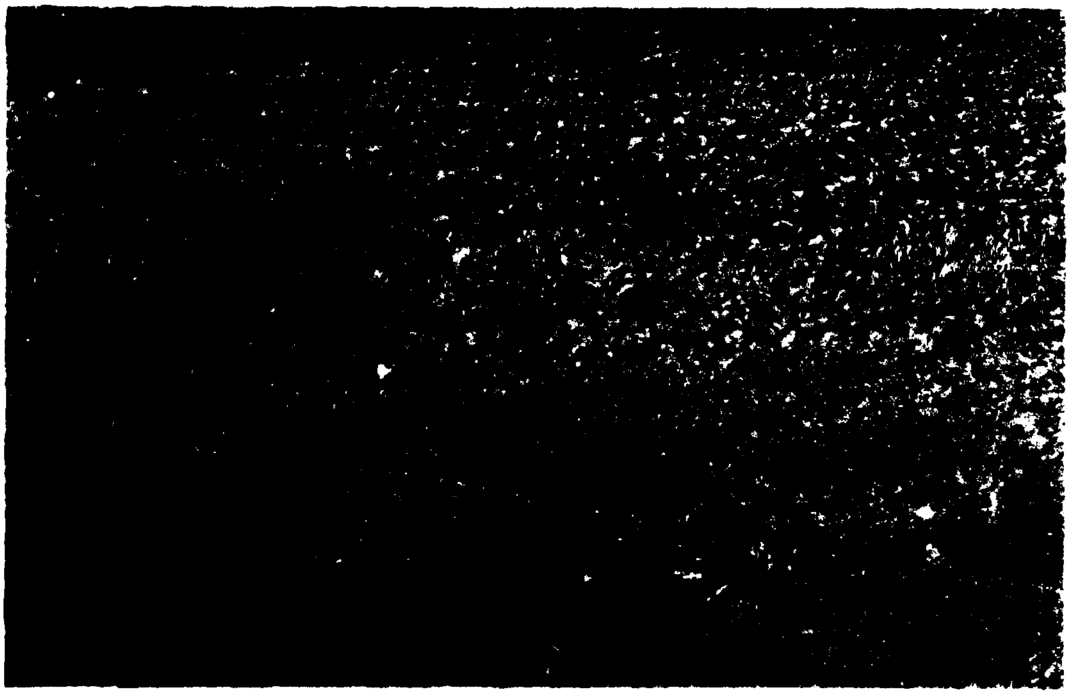
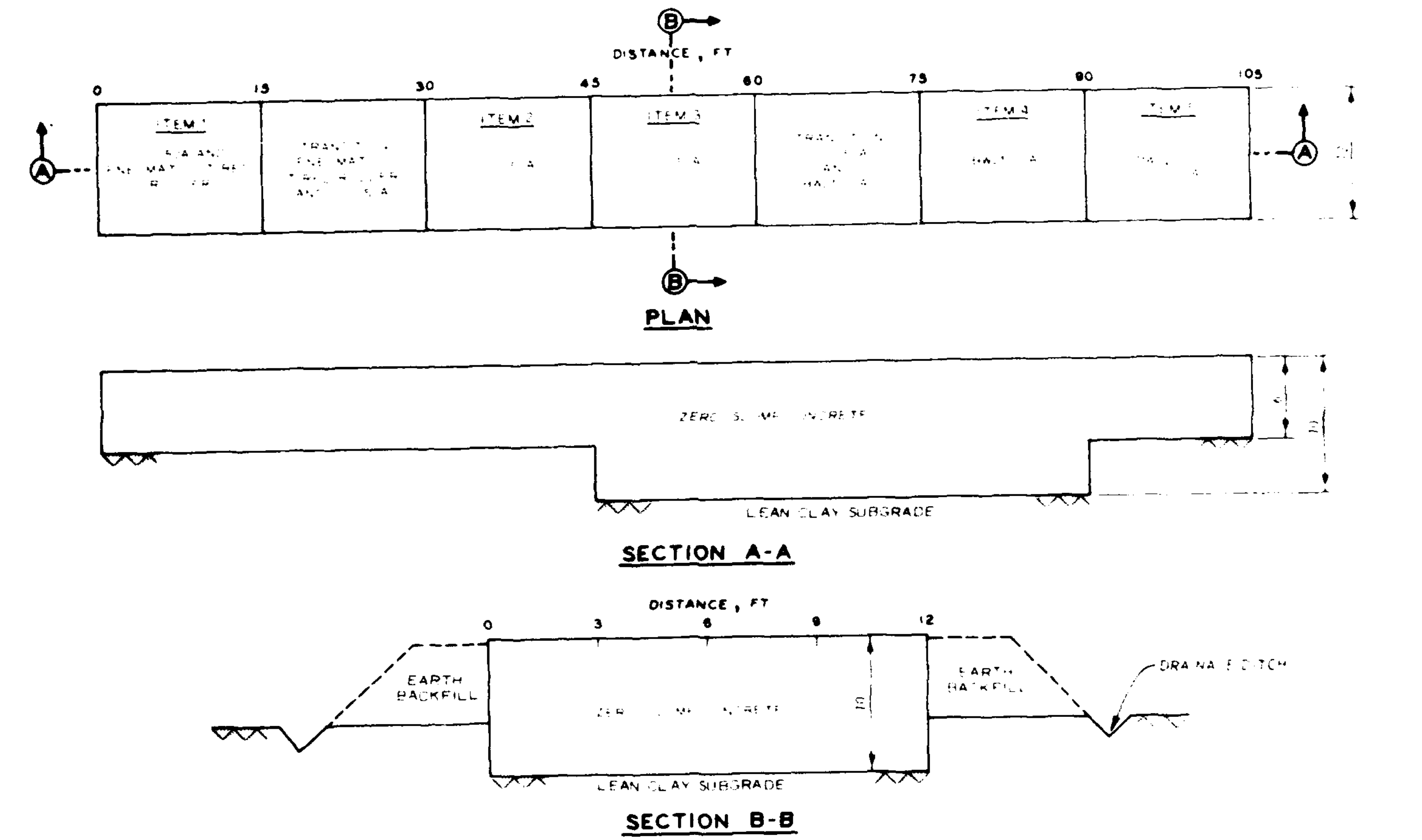


Photo 6. Surface texture of zero-slump concrete compacted by vibratory roller



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